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## Effects of Lateral Mass Screw Rod Fixation to the Stability of Cervical Spine after Laminectomy

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### Abstract

There are many cases of injury in the cervical spine due to degenerative disorder, trauma or instability. This condition may produce pressure on the spinal cord or on the nerve coming from the spine. The aim of this study was, to analyze the stabilization of the cervical spine after undergoing laminectomy via computational simulation. For that purpose, a three-dimensional finite element (FE) model for the multilevel cervical spine segment (C1-C7) was developed using computed tomography (CT) data. There are various decompression techniques that can be applied to overcome the injury. Usually, decompression procedures will create an unstable spine. Therefore, in these situations, the spine is often surgically restabilized by using fusion and instrumentation. In this study, a lateral mass screw-rod fixation was created to stabilize the cervical spine after laminectomy. Material properties of the titanium alloy were assigned on the implants. The requirements moments and boundary conditions were applied on simulated implanted bone. Result showed that the bone without implant has a higher flexion and extension angle in comparison to the bone with implant under applied 1Nm moment. The bone without implant has maximum stress distribution at the vertebrae and ligaments. However, the bone with implant has maximum stress distribution at the screws and rods. Overall, the lateral mass screw-rod fixation provides stability to the cervical spine after undergoing laminectomy.

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**Keywords:** Finite element analysis; cervical spine; decompression; laminectomy; lateral mass screw-rod fixation; stability

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## 1. Introduction

Cervical spine has seven bones (vertebra): C1 until C7. These bones are connected to each other by the intervertebral disc (IVD), facets joint, endplate and ligaments. In general, there are many cases of injury in the cervical spine due to degenerative disorder, trauma or instability. This condition may produce pressure on the spinal cord or on the nerve coming from the spine. Pressure on the spinal cord or on the nerve coming from the spine may cause the posterior neck pain on palpation of spinous processes and limited range of motion associated with pain [1-3]. Decompression procedure is one of the techniques that can be done to overcome pain at the cervical spine. One of the decompression technique is laminectomy. The lamina of the vertebra is removed in order to widen the spinal canal and create more space for the spinal nerves. However, this technique will cause instability that can produce abnormal motion in the spinal cord, increasing the potential for serious neurological injury. Currently, there are two techniques that are usually used to stabilize the spine which are lateral mass screw-plate fixation and lateral mass screw-rod fixation. Each of these implant described above have special advantages and disadvantages. For the lateral mass screw-plate fixation, although this technique has been shown to be safe and reliable, some drawbacks do exist. Some of the problem are plates are difficult to contour, screw position is constrained by the plate's entry holes, screw back-out can occur, plate systems are not easily adapted for extension to the occiput and risk of implant failure and loss of alignment [4]. The screw rod fixation is able to more effectively accommodate variations in size, spacing and morphology of the lateral masses. With this fixation, compressive or distractive forces can be applied [5-6]. Other than that, screw rod fixations have better biomechanical stability than posterior plate fixations and a lower complication rate. Hence, the aim of this project was to analyse the biomechanical effect of lateral mass screw-rod fixation to the stability of cervical spine after undergoing laminectomy.

## 2. Materials and method

### 2.1. Finite element model construction

Three-dimensional model of the cervical spine was reconstructed using Computer Tomography (CT) images. 3D models of vertebrae (C1-C7) were created by using Mimics software (Ver10, Materialise NV, Belgium). The 3D models were turned into surface triangular elements in CosmosWork (Ver 2009, Dassault Systems, USA).

### 2.2. Soft tissue construction

Other components such as ligaments, IVD and end plates were modeled based on vertebrae geometry and literatures. The size of nucleus pulposus was approximately 44% of total area for intervertebral disc. Both the top and the bottom of each vertebra are restricted with a thin  $\frac{3}{4}$  millimeter cartilaginous pad called the 'Vertebral End-Plate'. The biochemical morphology of the end-plates is extremely similar to that of the disc. The thickness of the endplates was 1mm and the shape followed the cerviture of the vertebral [7]. The superior and inferior facets of the cervical spine were constructed based on the shape of the vertebrae with the average thickness of 1mm [8]. The intervertebral discs, endplates and facets were modelled via SolidWorks (Ver 2009, Dassault Systems, USA). 5 major cervical spine ligaments were incorporated in the model, including the posterior longitudinal ligament (PLL), anterior longitudinal ligament (ALL), capsular ligament (JC), interspinous ligament (ISL) and flavum ligament (LF). The positions, area ( $\text{mm}^2$ ) and length (mm) of the ligaments were chosen based on the previous study [9-11]. CosmosWork (Ver 2009, Dassault Systems, USA) was used for generating mesh and finite element analysis.

### 2.3. The modeling of cervical spine after laminectomy

Lamina of vertebra at C4 until C6 were removed to widen the spinal canal and created more space for the spinal nerves. Surgical preparation of the bone was carried out prior to insertion of the implant. The implants were modelled in SolidWorks and then placed in their respective bone model and then converted into solid tetrahedral mesh.

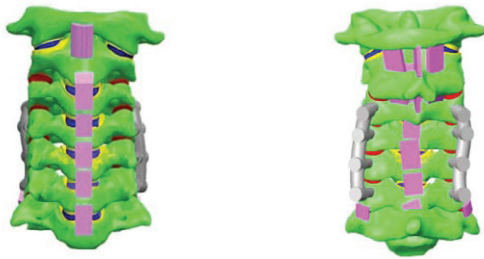


Fig. 1. 3 Dimensional finite element model for (A) the anterior side of the cervical spine; (B) the posterior side of the cervical spine

### 2.4. Material properties

The model was initially assigned material properties reported in the literature as common to the cervical spine. The bone models were allocated with a linear elastic isotropic material representing cortical bone ( $E=12000\text{MPa}$ ,  $\nu=0.3$ ). The implants were allocated homogeneous linear elastic material resembling titanium alloy material for rod and screws component ( $E=110000\text{MPa}$ ,  $\nu=0.3$ ). The endplates were also modeled using linear elastic material ( $E=100\text{MPa}$ ,  $\nu=0.2$ ) [12]. All the ligaments were modelled using SolidWorks and had been assigned as linear elastic isotropic. The position of the ligaments was estimated based on previously published anatomical studies [9-10, 12-13].

### 2.5. Specification of loading condition

The predicted responses were compared against the published experimental and existing analytical results under the same boundary and load configurations. The inferior surface of the C7 vertebral body was fully constrained. Pure moment loading of  $1.0\text{Nm}$  was applied to the C1 vertebral body along the various anatomical planes to simulate the various movements of the cervical spine under flexion and extension bending configurations.

## 3. Result

### 3.1. Validation

For the validation, the model was validated under extension load configurations using SolidWorks. The C4-C6 model was analyzed to evaluate the von misses stress and range of motion responds under pure moment loading of  $1.0\text{Nm}$  and compared against in vitro experimental measurements carried out by Panjabi et al.(1986), Moroney et al.(1988), Panjabi et al.(2001) and Chin (2001) [9, 12]. The mechanical response of the C4-C6 model under extension loading agreed reasonably well with the published experimental measurements as represented in Table 1.

Table 1. the comparison of results for ROM between the present C4-C6 models and experimental data under extension moments. [12]

	Extension (Degree)	
	C4-C5	C5-C6
Panjabi (1986)	3.6-7.5	3.6-8.0
Moroney (1988)	3.5	3.5
Panjabi(2001)	4.8	4.4
Chin(2001)	5.0	5.5
Current study	7.0	5.0

#### 2.4. Stress distribution

The information on the stress distribution of the cervical spine under flexion and extension with and without the implant is shown in Fig. 4. As it can be seen, the bone without the implant had maximum stress distribution at the vertebrae and ligaments. However, the bone with the implant had maximum stress distribution at the screws and rods under flexion and extension. The stress at the vertebrae and ligaments was very less.

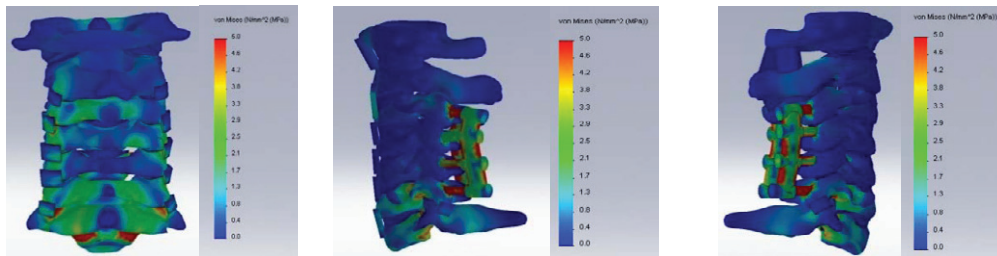


Fig. 2. Von misses stress distribution at the cervical spine (A) intact; (B) with the implant under extension; (C) with the implant under flexion

#### 2.5. Displacement

Fig. 5 shows the displacement of the bone with and without the implant under flexion and extension. As it can be seen, the bone without the implant had higher displacement especially at the C1 and C2 of 17 mm respectively. However, the bone with the implant under flexion and extension has smaller displacement of 3.68 mm and 3.98 mm respectively.

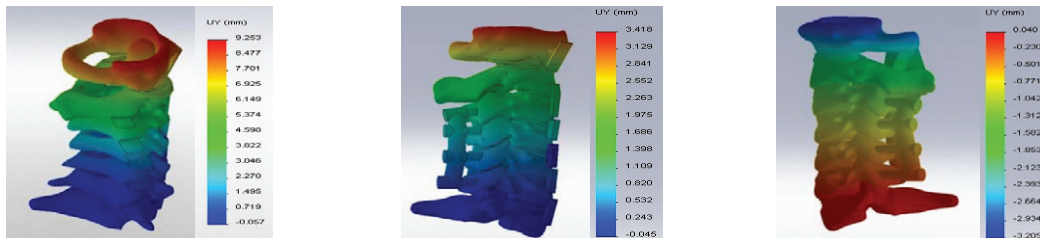


Fig. 3. Displacement for the bone (A) without implant; (B) with implant under extension; (C) bone with implant under flexion

### 3. Discussion and conclusion

Decompression procedure was one of the procedures that could be used to overcome the pain at the cervical spine such as laminectomy. As reported, laminectomy will lead to instability of the cervical. One of the suggested methods to improve the stability was to use lateral mass screw-rod fixation. To evaluate the biomechanical behavior of the lateral mass screw rod fixation, this study performed a finite element analysis (FEA) method to analyze stress distribution and range of motion of cervical spine with the screws and rod. We first validated our FEA model by applying the same loads from the literature to our model and compared the generated results which were displacement and stress after loading with that in literature [9]. The results showed comparable level to the results in previous experimental studies. With those results, we believed that our model provided convincingly accurate simulation of the C1-C7 motion segment and justified our results. The result of this study confirmed that the lateral mass screw rod fixation is capable to offer spine stability after decompression. According to the results, the displacement of the bones which were fixed with implant is low was clearly observed. The rigidity of the model increased because of increasing the number of fixation points. The rigidity is important to prevent excessive motion and reduce the pain at the cervical spine. Since this study was created under semi-static condition, the low displacement significantly indicated the stability of the implant fixation. Therefore, the fixation with lateral mass screw-rod fixation indicated to be reasonably better solution to enhance the stability of the implant.

Concerning the stress distribution, results illustrated that higher stress were generated at the implant under flexion and extension. From a mechanical view point, the stability of the implant was increased as a result of contact stress between the screws and rod with the vertebra. However, the higher of stress at the implant can cause the implant failure and bone collapse at the implant construct. Although more stress distributed at the screws and rod, but the stress was still much lower than the yield strength of the titanium alloy (848.4 MPa). This model demonstrated C6 and C7 which may indicate higher chances of failure because of greater compressive stress at the vertebra and facets joint while loaded, resulting in bone collapse and migration. This result indicating that facets joint transferred partial loads in all loading conditions. The screws and rods will have the maximum stress because of the material properties for the implant was higher than the bones. The Young's modulus for Ti-alloy ( $E=110\text{GPa}$ ) was much higher than that of cancellous bone (120MPa). Therefore, the screws and rods were more stiffness than the cancellous bones and will support the entire loads that had been applied to the cervical spine. It was concluded that this fixation successfully achieved stability because no values exceeded the yield strength of the bone and implant. Our data were based upon finite element analysis and hence lead several limitations with practical recommendations found in this study. First, this presented project performing only flexion and extension motion. Thus, wider physiological loading condition such as lateral bending and axial rotation would produce a better model of the cervical spine. Second, further enhancement of ligaments must consider the correct measurement of length, cross-sectional area, shapes and the stress-strain behavior of the ligaments due to the viscoelastic mechanical properties of spinal ligaments are important for maintaining spinal stability. Third, the screws in this study were designed without the thread and lacked of information regarding the main determinants of screw pullout resistance which are major screw diameter and thread depth.

This presented paper was successfully demonstrated the biomechanical behaviour of the fixation methods of the lateral mass screw rod fixation. Based on the results and presented discussions, implantation with lateral mass screw rod fixation after laminectomy successfully restores the stability of

the cervical spine. This stability was interpreted with lower bones displacement as well as considerably sufficient stresses value to provide fixation.

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